

# Observing Planetary Rings with JWST: Science Justification and Observation Requirements

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## 1. Introduction

The rings that adorn the four giant planets are of prime importance as accessible natural laboratories for disk processes, as clues to the origin and evolution of planetary systems, and as shapers as well as detectors of their planetary environments (Tiscareno, 2013). The retinue of small moons accompanying all known ring systems are intimately connected as both sources and products, as well as shepherds and perturbers, of the rings. Leading sources of data on ring systems include spacecraft such as *Cassini* and *Voyager*, but also space telescopes such as Hubble (HST) and Spitzer (SST) as well as ground-based telescopes.

The James Webb Space Telescope (JWST) is being prepared for launch in 2018 to begin a planned five-year mission. JWST will have the capability to observe solar system objects as close as Mars. Although most of the hardware is already designed and under construction if not completed, work continues on the development of operations guidelines and software and the completion of calibration tasks. The purpose of this white paper is to identify observations of planetary rings that might be undertaken by JWST and to describe what is required for JWST to accomplish those goals.

## 2. Capabilities and Justifications

### 2.1. Imaging of faint objects

In the context of rings, observations of faint targets are complicated by the nearby presence of the bright planet. Strategies are needed to enhance the apparent brightness of desired targets and/or to suppress the apparent brightness of the planet.

JWST will be (see Section 3.2) equipped with filters that allow it to image giant planet systems at wavelength bands in which the planet is greatly darkened by atmospheric absorption due to methane and other atmospheric constituents. For observations of faint moons or rings that are close to bright giant planets, this will lead to greatly improved signal-to-noise and spatial resolution compared to HST and other observatories operating in the same wavelength bands (put another way, JWST will operate within the infrared methane bands at a spatial resolution comparable to that at which HST operates in visible bands, with vastly improved signal-to-noise when suppression of glare from the planet is an important factor).

As a result, JWST will provide major advances in resolving and separating the main rings of Uranus and Neptune, improving upon HST and ground-based observations of their fine structure (de Pater et al., 2005, 2006, 2007; Showalter and Lissauer, 2006).

JWST will have new sensitivity to yet-undiscovered small moons or faint rings, including the predicted rings of Mars (Showalter et al., 2006) and Pluto (Steffi and Stern, 2007). The *New Horizons* spacecraft, whose flyby of Pluto will pre-date JWST, will likely not have the last word on Pluto's possible rings due to its flyby speed and limited range of viewing geometries. JWST will be ideal for follow-up observations, possibly with greater sensitivity, and can also search for rings around other trans-Neptunian dwarf planets.

JWST will serve as an important window on the outer solar system for imaging Targets of Opportunity such as the Jupiter impact of 2009 (Hammel et al., 2010) and the Saturn storm of 2010-11 (Sayanagi et al., 2013).

Continuing to observe and track objects that are faint, recently discovered, or known to be changing is of high importance. JWST observations will be important for continuing to track the chaotic orbits of Prometheus and Pandora (Goldreich and Rappaport, 2003) and Mab (Kumar et al., 2012), the evolving ring arcs of Neptune (de Pater et al., 2005), progressively winding ripple patterns in the rings of Jupiter and Saturn that trace cometary impacts (Hedman et al., 2011; Showalter et al., 2011), and other faint targets.

It may also be capable of tracking the azimuthal arcs or clumps in the rings of Jupiter (Showalter et al., 2007) and the “propeller” moons embedded in Saturn’s rings (Tiscareno et al., 2010).

Imaging of faint objects with JWST may be further enhanced by coronagraphy (see Section 3.3).

## 2.2. Spectroscopy of faint objects

The compositional diversity of solid objects in the outer solar system is apparent from the near-infrared spectra of bodies such as Triton, Pluto and Charon, which show absorption features of varying strengths due to varying amounts of methane, water and other ices on their surfaces. The smaller moons and rings of Neptune might have originally been made of the same stuff as these larger objects, but they also would have had much different evolutionary histories (perhaps less thermal processing, more pollution from infalling matter, etc.). Comparing the surface composition of these smaller objects to their larger neighbors should therefore help clarify the origins and histories of both, but it is difficult to obtain good-quality spectra of these very small and/or faint objects from ground-based observatories.

With its large mirror and high-quality spectrometer, JWST will be able to take spectra of very faint objects. Potential targets include the rings and small moons of Uranus and Neptune; these have never been the subjects of high-fidelity spectroscopic study, as Voyager 2 did not carry a spectrometer capable of detecting them, and characterizing their chemical compositions is of considerable interest for addressing the origins of the Uranus and Neptune systems as well as for addressing the question of why the Uranian and Neptunian rings are so qualitatively different from those of Saturn (Tiscareno, 2013).

By the same token, JWST will be able to acquire very sensitive spectra of all objects over a broad range of wavelengths. It will be able to fill in the gap between Cassini VIMS and Cassini CIRS (from 5 to 8 microns) and will be able to map Saturn’s rings in the 1.65-micron water absorption feature (which falls in an internal gap in VIMS’ spectral coverage and is unusual in that its depth is useful for mapping temperature variations). Its spatial resolution will be comparable to CIRS, and its sensitivity will be greater, so it should be capable of improving current maps of Saturn’s rings in the thermal infrared (though over a very limited range of phase angles) and may achieve the first detection of the faint silicate absorption features at  $\gtrsim 10$  microns, yielding information about the little-understood non-water-ice components of Jupiter’s and Saturn’s rings.

Spectroscopy of faint objects out to 5 microns with JWST may be further enhanced by coronagraphy (see Section 3.3).

## 2.3. Equinox

The next Saturn equinox will take place in 2025. The event itself will not be observable by JWST, as it will occur when Saturn is near the Sun as seen from Earth, but low sun angles will be observable approximately three months before and after equinox. This will facilitate the observation of seasonal phenomena such as spokes, which are prevalent near equinox and absent near solstice (Mitchell et al., 2006, 2013). JWST will have sufficient resolution to continue monitoring spokes, as has HST (McGhee et al., 2005), which will have particular value after the end of the *Cassini* mission. JWST will also be able to improve on the tracking of clumps in and around the F Ring near equinox (McGhee et al., 2001), and will enjoy optimal edge-on viewing of Saturn’s dusty rings<sup>1</sup> during this season (de Pater et al., 1996, 2004).

Neither Uranus nor Neptune has an equinox that falls within the JWST mission (Meeus, 1997). During the JWST mission, Sun angles will decrease at Neptune (solstice 1997, equinox 2038), and will increase at Uranus (equinox 2007, solstice 2030). This will lead to increasingly favorable viewing for both systems as the JWST mission progresses, since Neptune’s rings are primarily dusty while Uranus’ rings are dense and sharp-edged. The only exact equinoxes possibly observable by JWST will be at Jupiter; these will provide optimal viewing of vertical structure in the halo/gossamer rings.

# 3. Action Items

## 3.1. Stray light and extended point-spread functions

Because faint rings and small moons are often in close proximity to the bright planet about which they orbit, it is important to characterize the stray light (SL) and extended point-spread function (EPSF) of JWST instruments to determine how close to the planet an object can be and still be observable.

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<sup>1</sup>The Phoebe ring, which lies in Saturn’s orbit plane and is *always* edge-on as seen from Earth, is thus always available for optimal edge-on viewing.

The point-spread functions are well characterized for point sources within the field of view, but EPSFs need to be compiled from these for extended objects, especially when the planet is off the edge of the field of view. Preliminary analysis of stray light should also be characterized through studying the blueprints of the telescope and instruments, and later by testing on the ground after the spacecraft is built. It should be kept in mind that the severity of stray light might be different at different wavelengths. The limited roll ability of the JWST spacecraft makes this issue more pressing, as observation targets cannot often be oriented so as not to coincide with stray light patterns.

### 3.2. Color filters

Imaging of faint objects is enhanced at wavelength bands in which the planet is dim, especially at absorption features of atmospheric constituents such as methane (see Section 2.1). The methane absorption feature at 2.3 microns is strong, and corresponds to a wavelength at which water ice is bright. However, JWST does not have a filter centered on 2.3 microns. Study is needed to determine whether imaging at 2.3 microns might be facilitated by selecting the appropriate wavelength of a NIRSpec cube using Integral Field Units (IFUs), and also whether this mode offers imaging quality as envisioned in Section 2.1. This is especially germane for Jupiter and Saturn, which are too extended to provide a basis for adaptive optics, giving JWST a more pronounced advantage over ground-based telescopes. Study is also needed to determine whether filters centered on 1.8 microns and on 3.4 microns can offer comparable imaging quality.

### 3.3. Coronagraphy

Both imaging and spectroscopy of faint objects (Sections 2.1 and 2.2) can be enhanced near a bright planet by using the NIRSpec instrument in its Microshutter Array (MSA) mode, which suppresses the brightness of the boresighted planet by  $10^{-4}$  while taking spectrally-resolved images. Stray light problems (see Section 3.1) would likely be minimized with the bright planet on the boresight, increasing the attractiveness of this technique.

Further study is needed to characterize whether the MSA mode will facilitate good observations of faint rings or moons. For example, is the attenuation of the planet by  $10^{-4}$  sufficient? Would the angular size of Jupiter render it too large to be suppressed by this technique?

### 3.4. Stellar occultations

Stellar occultations, in which the brightness of a star is continuously monitored as it passes behind a semi-transparent object such as a ring, can distinguish very fine structural details, often superior to the detail discernible by direct imaging albeit along only a single dimension (e.g., Bosh et al., 2002; Hedman et al., 2007). Occultations are an excellent method for determining the precession rates of rings, leading to tight and otherwise unobtainable constraints on planetary interiors. The primary requirement for a successful occultation is fast read-out time. Spectrally integrated brightness measurements are adequate, though spectral resolution adds further potential for discovery (e.g. Hedman et al., 2013).

Further study is needed to characterize whether stellar occultations are feasible with any JWST instruments. One possibility might be to use NIRCcam with filters, which can take advantage of the relative dimness of giant planets in the near infrared.

## 4. Conclusion

JWST promises to be an unprecedentedly valuable observatory for observing planetary rings and their attendant small moons. We encourage the observing community to use the ideas in Section 2 to formulate observation plans. We encourage the JWST project to address the items in Section 3 in order to ensure the highest possible quality of observations. Because the post-launch servicing missions that were crucial to the success of HST will not be possible for JWST, it is imperative for both communities to identify and resolve any outstanding issues now or in the near future.

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